(12) UK Patent Application (19) GB (11) 2 250 093(13) A

(43) Date of A publication 27.05.1992

(21) Application No 9025164.6

(22) Date of filing 20.11.1990

(71) Applicant
Graeme William Younger
West Lodge, Ratho Park, Newbridge, Midlothian, EH28 8NX, United Kingdom

(72) Inventor
Graeme William Younger

(74) Agent and/or Address for Service
H. Aspden
Acres High, Hadrian Way, Chilworth, Southampton, SO1 7HZ, United Kingdom

(51) INT CL^5
G01S 11/14 5/22

(52) UK CL (Edition K)
G1G GRE G3S

(56) Documents cited
GB 2156986 A EP 0180652 A1

(58) Field of search
UK CL (Edition K) G1G GER GRA GRE GSB
INT CL^5 G01S 5/18 11/14

(54) Ultrasonic position measuring system

(57) A receiver sensitive to ultrasound pulses measures the relative position of a transmitter at a test position by analysis of a recurrently updated transient signal wave pattern (I in Fig. 4) of a received ultrasound signal stored in a data memory. By sensing the arrival of the signal (II) a detector is conditioned to respond to a later polarity reversal (the fifth in Fig. 4) centred on a time window (III). The time of this reversal in relation to ultrasound pulse emission from the transmitter is the distance measure of the test position. The invention is suitable for measuring the position of the transmitter when this is in contact with a vibrating structural member, eg an aircraft frame. Two receivers may be spaced apart along a baseline for position location by a triangulation method.

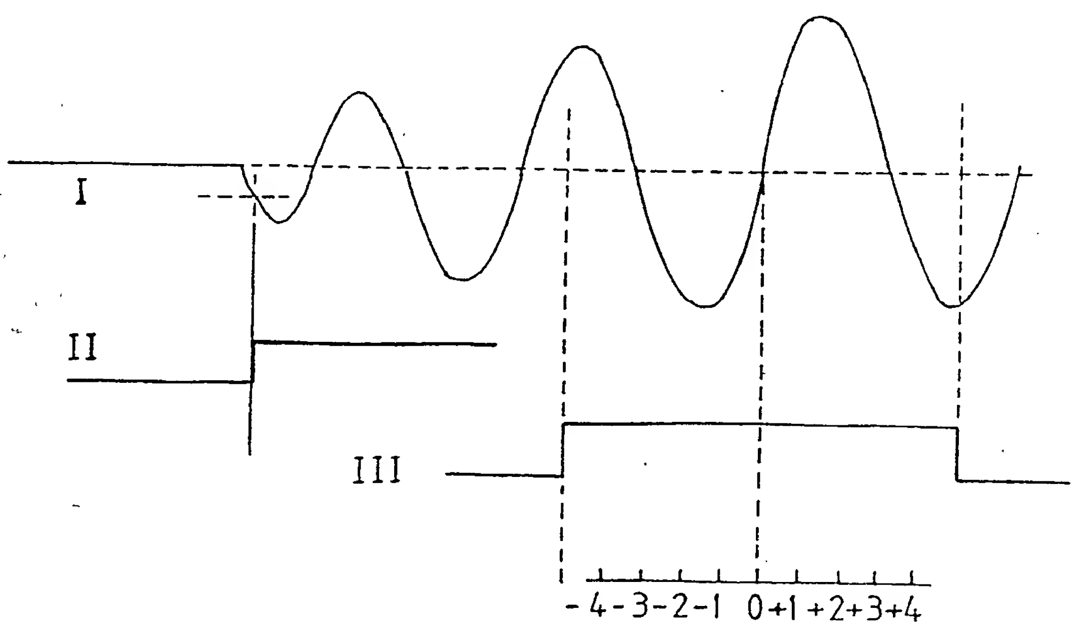

FIG. 4

GB 2 250 093

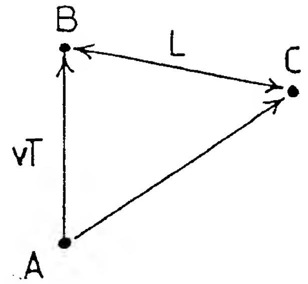

FIG. 1

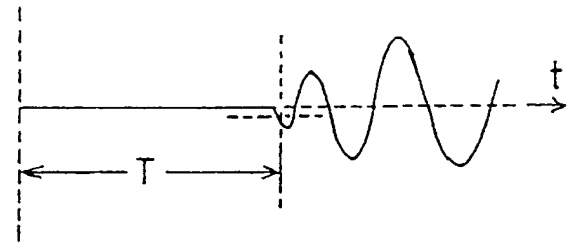

FIG. 2

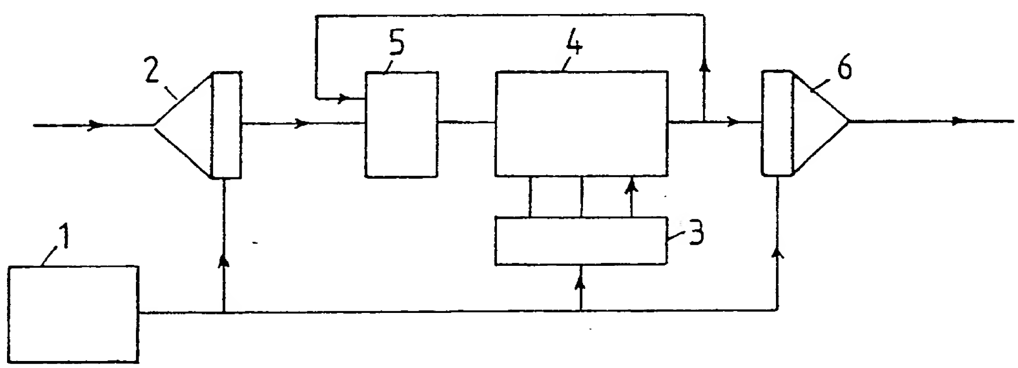

FIG. 3

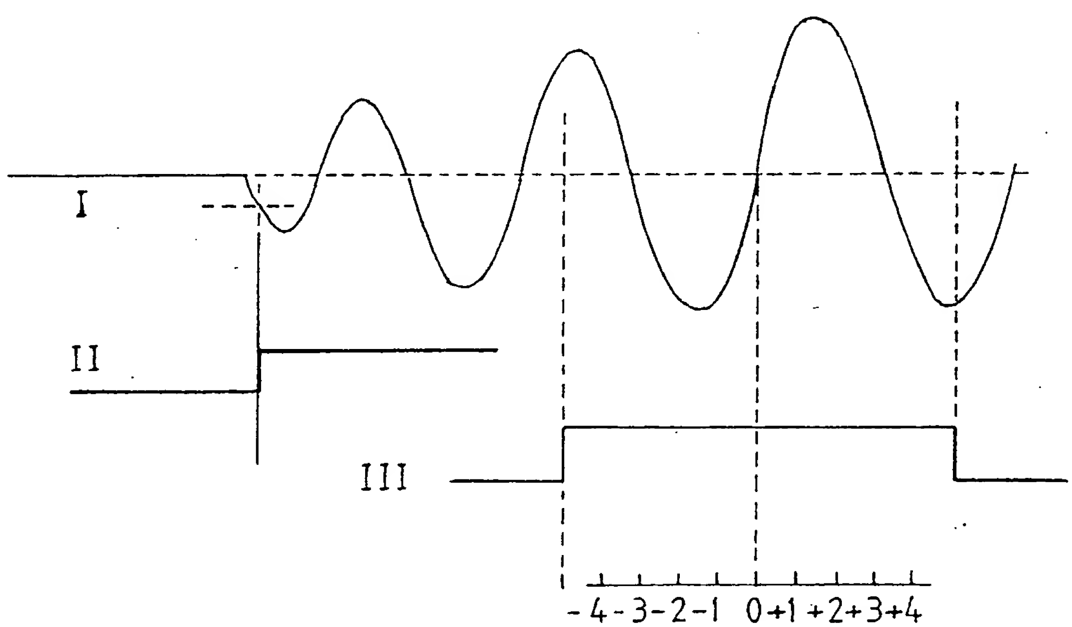

FIG. 4

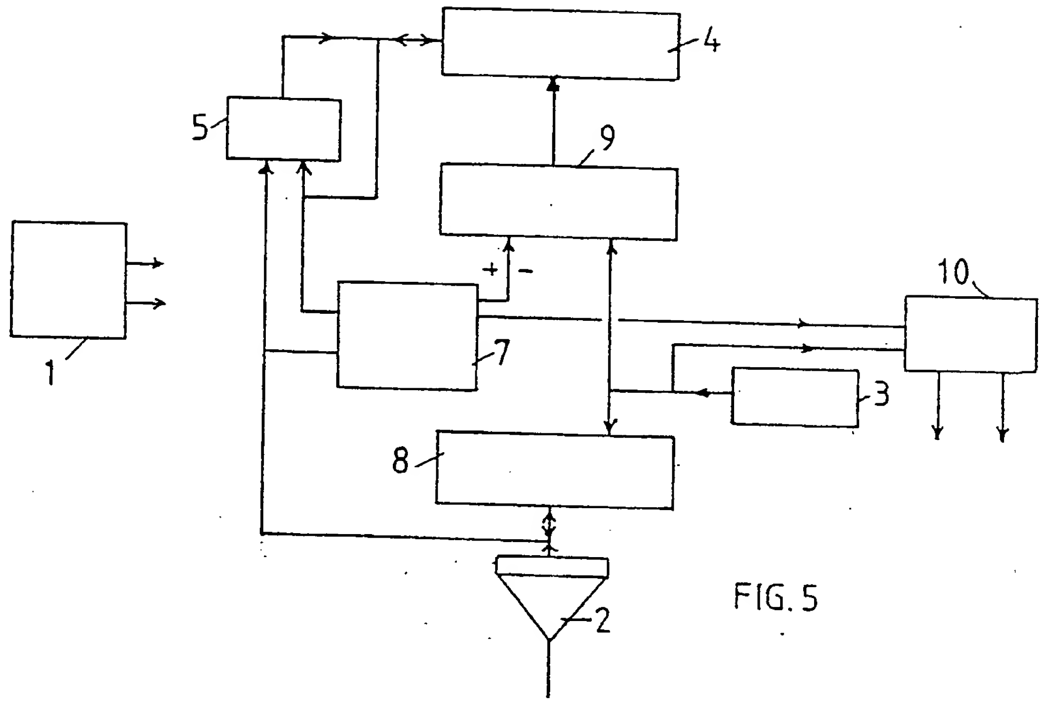

FIG. 5

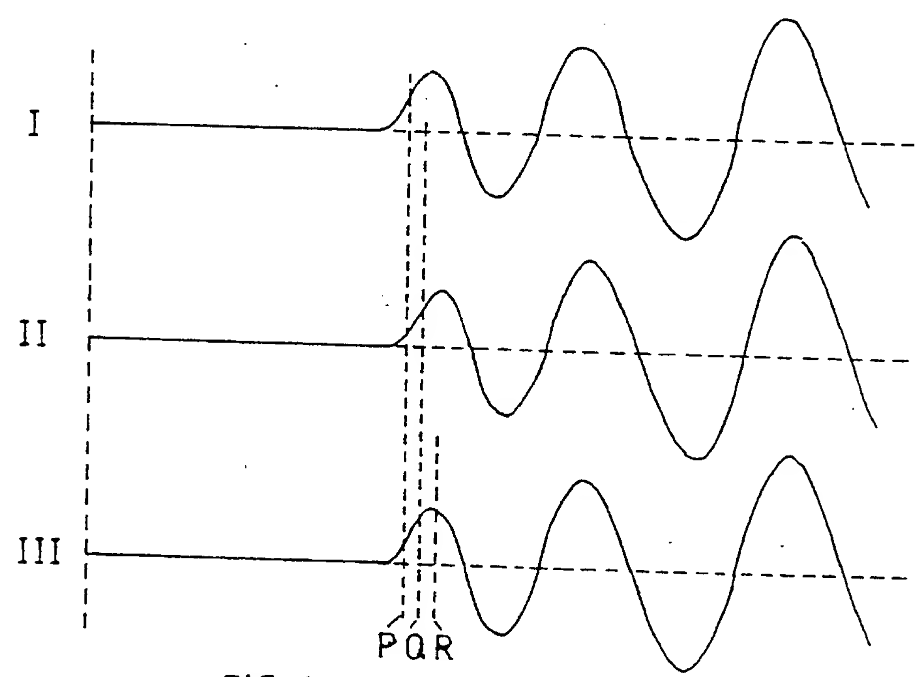

FIG. 6

ULTRASONIC POSITION MEASURING SYSTEM

FIELD OF INVENTION

This invention relates to a system of position measurement which operates by sensing ultrasonic signals. By sensing 'position' the system has the means for sensing rate of change of position and so a state of vibration of a particular position. Thus the field of this invention extends to systems which can be used for test purposes, including the remote sensing of a vibrating surface. Indeed, the system to be described developed from research on a portable ultrasonic non-destructive-test inspection and data recording system for the mapping of defects in wing and frame structures as used in aircraft. The testing of aircraft structures by ultrasonic sensing poses special problems and this invention finds particular application to problems of this kind.

BACKGROUND OF THE INVENTION

When testing the behaviour of the frame structure or wings of an aircraft it is possible to use two ultrasound receivers placed a predetermined distance apart to form a base line from which the relative position of a free-moving NDT (non-destructive testing) ultrasonic probe is to be measured. An airborne ultrasound transmitter, meaning one sensitive to the speed of ultrasound vibrations in air, is mounted on the probe and this emits pulses at predetermined intervals. These pulses are

detected by the receivers. Then, from the measured propagation delay, the range distances can be calculated and, from knowledge of the base line length, the position of the probe relative to the receivers can be determined. Preferably, such tests are made in still air, as within an aircraft hangar or laboratory, but this does not preclude use of the invention in an open environment, as for the testing of bridge structures, for example.

This technique, as used hitherto, has suffered from external interference both from a lack of adequate signal to noise ratio and also from external sources of ultrasound interfering with the frequency used. It is the object of the subject invention to overcome these weaknesses in a novel way, which has distinct advantages and which has proved itself under test conditions by providing reliable measurements with a 0.5 mm. resolution of distance measurement.

BRIEF DESCRIPTION OF THE INVENTION

According to the invention, an ultrasonic position measuring system comprises an ultrasonic wave transmitter at a test position A in a test structure, a receiver sensitive to ultrasound at a position B and producing a transduced electrical signal representing the received ultrasound waveform, an electronic circuit including a pulse generator and data analysis means for sensing a

predetermined transition in the transduced signal and registering the time of that transition in relation to the generator pulse timing, the system being characterized in that the transition sensed by the data analysis means is that of a retarded fluctuation in the received ultrasound waveform following the sensing of the onset of the transduced electrical signal.

According to a feature of the invention, in the ultrasonic position measuring system the ultrasound content of the transmitted signal is produced by a fixed frequency oscillator, the output from which is admitted in pulses to an acoustic transducer which generates the transmitted signal and the data analysis means responds to the fluctuations in the received ultrasound waveform by sensing a predetermined polarity reversal of the waveform following the onset triggered by sensing the arrival of the received pulse.

According to a further feature of the invention, the data analysis means are operative to register the occurrence of the transition for which the predetermined polarity reversal is the fifth transition through zero signal.

According to another feature of the invention, the data analysis means are controlled by a systems clock and a counter which control the sampling of incoming signal data

at B at a sequence of time intervals related to distance from A and comprises a data store and comparator means for separately sensing the event when a signal arrives and the event when the signal undergoes the predetermined polarity reversal, the first event triggering the reversal count determining the selection of the reversal of the second event, the timing of the second event being registered in the memory of the data store and the timing data so registered providing the measure of distance indicated by the system.

According to a further feature of the invention, the data analysis means comprise also a data averaging memory which registers a profile of the received signal waveform averaged by recycling memory data through a summing unit which combines a weighted measure of the recycled data with current input data, the means for sensing the event when a signal arrives and the event when the signal undergoes the predetermined polarity reversal being responsive to the signal represented by the data-averaged waveform profile as registered in the data averaging memory, whereby to afford a measure of AB based on an average generated from a muliplicity of recurrent pulses of ultrasonic transmissions.

According to a further feature of the invention, the data analysis means includes a buffer memory for temporary

storage of incoming signal waveform profile data provided by the currently incoming pulse, and the means for detecting the predetermined polarity reversal comprise a comparator means sensitive to control data from the data averaging memory which governs the determination of the predetermined polarity reversal in incoming data registered in the buffer memory.

According to a still further feature of the invention, the data averaging memory includes two memory banks which are controlled so as to cooperate in responding alternately to incoming signal profile data and adjusting the averaged data stored in memory, data at successive addresses representing distance measurement being read from one memory bank and merged with data from the buffer memory before storage in the other memory bank.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 depicts a triangular ranging layout for testing the position of transmitter A by sensing signals at B and C.

Fig. 2 shows a typical signal transient sensed at B.

Fig. 3 shows a schematic circuit used for the analysis of the signal transient depicted in Fig. 2.

Fig. 4 portrays characteristic features of the signal transient as utilized in a specific implementation of the invention.

Fig. 5 shows a more detailed schematic circuit used for analysis of the signal transient in accordance with one aspect of the invention.

Fig. 6 shows waveform versions of the transient signal to support the decription of the operation of the circuit in Fig. 5.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Fig. 1 an ultrasonic transmitter mounted on a probe at position A is deemed to emit pulses which are intercepted by two ultrasonic receivers, one at B and one at C, these being at fixed positions spaced apart by a distance D on a frame of reference.

Thus B and C may be fixed in a rigid frame member of an aircraft, for example, and A might be that of a probe in contact with the surface of a pliable and vibrating part of the aircraft structure.

By measuring the distances AB, AC in terms of the sound propagation intervals from A to B and A to C, assuming that the speed of sound is known, the triangulation method of computing the position of A allows that position to be determined. BC is a fixed and known distance L.

Given that the ultrasonic pulse emitted by the probe at A is a step pulse arising from the sudden switch-on of a

modulating signal oscillation at an ultrasonic frequency at time t = 0, the delay T before the signal is sensed at B is a measure of AB. As shown in Fig. 2, the signal received at B will build up progressively as a transient oscillation, its waveform being a function of the distance AB and the phase condition of that modulating signal at the moment of switch-on.

Now, in order to sense the arrival of that signal at B, the leading edge of the received signal waveform has to be detected by a threshold comparator of some kind. To maximize the amplitude of this edge, and so enhance the speed of detection and reduce uncertainty in measurement, the system bandwidth must be kept wide. This is in direct conflict with the need to maximize the signal to noise ratio. In addition, the particular nature of the signal excludes all normal filter techniques.

For this reason the signal filter system shown in Fig. 3 has been devised. It operates by virtue of the speed-of-light electronic communication between the probe excitation and the circuit of the sensing system, which allows virtually instantaneous timing of controls in relation to the speed-of-sound measurement. At the pulse start time t = 0 referenced in Fig. 2, the system clock 1 is started. This controls the analogue to digital converter (ADC) 2 and the address counter 3. The

'address' is to be regarded as a measure of the distance from A reached by the emitted pulse waveform at any instant. Thus by using a multiplicity of address locations determined by the system clock timing, each location can be used to register the strength of the signal waveform at the specific position determined by the clock timing. The reference is the pulse start time t = 0.

This supposes that, in measuring AB, the signal filter shown in Fig. 3 is that associated with the ultrasonic receiver at B, just as a separate duplicate circuit would serve to measure AC. Alternatively, for certain applications, the same filter circuit could be used by multiplexing the two ranges and switching the circuit cyclically between the receivers at B and C.

The incoming signal is sampled by the ADC 2 and converted to digital form at a rate well in excess of the minimum Nyquist rate to conserve waveform. The content of each location in digital memory 4 defined by the address registered in the address counter 3 is caused to be averaged over a repeated pulse cycle sequence. This involves the combination of the incoming digital data from the ADC 2 with weighted feedback data from the address location in memory 4. The progressive update of the address data involves combining the input and the feedback in the summing unit 5 and using that to update, at an

address in the memory location, data in store to represent the newly generated average signal strength. This occurs for each address location corresponding to the pulse repetition period so that the resulting data in store is representative of the received signal strength over that period. This period includes the propagation time T and it is from the rise in strength or leading edge of this averaged signal profile that T is determined.

In practice, the system as so far described, which includes the point by point averaging of the received signal waveform, performs a very effective time average of a time-stationary signal and improves the signal to noise ratio by a substantial factor closely dependent upon the weighting factor used in that address feedback feature.

However, whereas what has been described operates very satisfactorily for stationary and very slow moving probe sources, it is unable to provide high resolution sensing of probes on surfaces that are in vibratory motion. The subject invention has the objective of satisfying this application to the tracking of rapidly changing range and so sensing position of a moving ultrasonic source.

Fig. 4 shows a typical time average signal waveform such as is provided as output from the DAC 6 in Fig. 3. This waveform (denoted I) can be used as a measure of the

distance AB by taking the time to the detection of the leading edge (step in waveform denoted II) and applying an address correction based on the sampling of the non-averaged incoming signal waveform. The latter allows the dynamic state of the probe to govern the indicated measure, but the address correction is based on a sampling of the signal during a specific time slot or window (III) related to the position of the leading edge of the averaged signal waveform.

As shown in Fig. 4, the window (III) is set around a crossover point of the time averaged signal waveform stored in the memory 4. The third rising crossover point has been found to be optimum for the intended purpose, which is to establish a time independent of signal amplitude. Assuming the polarity of the transient signal derived by transducing the ultrasound has the form shown, with the initial signal going negative, the third rising crossover point is used. This choice is found to have optimum advantages. It is much better defined, owing to its higher rate of change than that at the first crossover and therefore the instantaneous signal to noise ratio is better and a sharper definition of the transition can be established. Note that, ignoring polarity, this is the fifth crossover point following signal onset.

The window defines the range of address locations either side of the crossover point and the signal values stored in these locations, as identified by the number scale in Fig. 4, are summed either side of the address of the crossover point and compared to provide the regulation which adjusts the reference location address of the third rising crossover point in the averaged signal waveform. This is the function of the comparator circuit 7, as shown in Fig. 5. The use of this window avoids aliasing problems.

The system in Fig. 5 is subject to the timing control of the system clock 1 and the address counter 3, which has an input to memory 8 and the memory 4 via the summing unit 9. The summing unit 5 in Fig. 5 discharges the same function as unit 5 in Fig. 1, combining weighting data by feedback with the new input from the ADC 2. The summing unit 9 operates in a similar way to weight the address correction data supplied by comparator 7 so as to average the data record concerning the the third crossover point in the rising section of the signal waveform.

The incoming unaveraged signal which is converted by the ADC 2 in Fig. 5 is also examined in the window defined in Fig. 4 in the same way as a separate function of the comparator circuit 7 and a comparison is made in that circuit between a predetermined reference address value of

the crossover point of the averaged signal waveform applicable to a stationary condition of the probe at A or slowly changing value of AB. It will be understood that, if the system senses a vibration of position, there will be an initial stationary condition which can be established as a basis for reference, then there will be an averaged location of the crossover point, which is effectively a measure of the transient position of A relative to B and, in addition, there will be the instantaneous input of a location address derived from the crossover point in the incoming unaveraged signal waveform.

The address of the crossover point in the incoming signal from ADC 2 is compared with the address of the stationary signal crossover point in comparator 7 and, if the range AB has altered from the previous ranging cycle, an address correction is calculated. This correction is used to modify the address in the memory 4 at which the new average is stored.

Until the crossover point is known, just after the third wave for detection of the third rising crossover point in the signal waveform shown in Fig. 4, the address correction to be applied is unknown. To overcome this the output from ADC 2 is stored in the buffer or temporary memory 8 with an unmodified address. When the crossover

point is determined in comparator 7 from the input signal from ADC 2, it is stored in the comparator but not acted upon until the next cycle. A similar problem exists when writing to the modified address in that, for changing range, new address data will overwrite data which are still required. To overcome this the main memory 4 in which the signal average is stored is divided into two banks of address locations used to record the computed average and these two banks are used alternately, by reading from one and writing to the other.

To understand this, reference is now made to Fig. 6. Here there are three waveforms denoted I, II and III, respectively, and each is discussed in relation to an address position, denoted P, Q or R, respectively. Waveform I refers to the averaged signal stored in one bank of address locations in memory 4. Waveform II refers to the incoming signal from which an address correction is to be computed. Waveform III refers to the new average stored after correction in the other bank of address locations in memory 4.

Although the signal waveforms are depicted in analogue form, they are processed and stored in digital form, the reconstituted analogue waveform produced by the output converter DAC 6 (shown in Fig. 4) being synthesized by

reading successive memory addresses and feeding the contents through this digital to analogue converter.

Referring again to Fig. 6, at a given clock time the signal amplitude data of waveform I at address P is averaged on a weighted basis with the corresponding data of waveform II at address Q and stored at Q in the alternate bank of memory 4 to produce a corrected data version as waveform III.

Note that if the corrected data were fed into the original memory bank the data at address Q would be destroyed before being used at the next clock time to generate the new averaged value for registration at the next address R. By interchanging the roles of the two alternate banks of memory as the signal data ripples through in updating the memory a representative averaged waveform is always available for the ongoing computation of the address of the selected crossover point, which affords a measure of the position of B in relation to the transmitter at A.

In a typical circuit using the above principles, for each address there is a sample of the waveform digitized to 8 bits. To retain resolution in the average, 16 bits are used in two bytes.

The basic cycle which relates to the signal value at a single data point address location is then split into four phases, as follows:

Phase 1. Read most significant byte (MSB) average from modified address (memory 4) and read last data entry from unmodified address (memory 8).

Phase 2. Read least significant byte (LSB) average from modified address (memory 4).

Phase 3. Write new MSB average in memory 4 at modified address, sample and convert new input via ADC 2.

Phase 4. Write new LSB average in memory 4 at modified address and write new input at unmodified address (memory 8).

Referring to Fig. 5, data from the address counter 3 and the address correction data from comparator 7 is also supplied to the latch circuit 10. This latch circuit is reset to start a cycle at the pulse repetition frequency. It also provides the range data measurement consisting of the adjusted address number corresponding to the position of the crossover point. Computation means (not shown) then operate from the range data of the two reception channels of the receivers at both B and C plus data input defining the system parameters, such as scaling factors and the distance L in Fig. 1, to compute and record or indicate the position measurement of A.

Multiplexing techniques, and the data computation techniques, as well as the design details of electronic components which function as individual components in the manner described by reference to the drawing are familiar to those skilled in the electronics and computing arts. However, the combination of the components for the purpose described in this specification is novel and the invention provides advantages in dynamic position measurement which can be most useful in the testing of structures subject to vibration and stress.

In a test system using this invention the ultrasonic frequency is 70 kHz. The measurements of AB and AC are achieved by multiplexing. The four phases of the sequential address adjustments take 0.8 microseconds and the two ranges are multiplexed giving a sample rate of 1.6 microseconds. 8 samples per ultrasonic cycle (Nyquist factor 2) are achieved. A weighting factor of 64 used for the address averaging process gives an 8 to 1 improvement in the effective signal to noise ratio. The update period or pulse repetition rate is limited by the maximum range required and by reflections from nearby surfaces. However, a practical pulse repetition frequency has been found to be that of a period of 7 milliseconds, which allows a tracking range rate of 150 mm per second. A resolution in position measurement of 0.5 mm is achieved. The tracking range rate of 150 mm per second arises,

allowing for some degradation, from the wavelength of ultrasound in air at speed of 330 m/s being 4.7 mm with a pulse repetition rate of period 7 milliseconds.

CLAIMS

1 An ultrasonic position measuring system comprising an ultrasonic wave transmitter at a test position A in a test structure, a receiver sensitive to ultrasound at a position B and producing a transduced electrical signal representing the received ultrasound waveform, an electronic circuit including a pulse generator and data analysis means for sensing a predetermined transition in the transduced signal and registering the time of that transition in relation to the generator pulse timing, characterized in that the transition sensed by the data analysis means is that of a retarded fluctuation in the received ultrasound waveform following the sensing of the onset of the transduced electrical signal.

2 An ultrasonic position measuring system according to claim 1, wherein the ultrasound content of the transmitted signal is produced by a fixed frequency oscillator, the output from which is admitted in pulses to an acoustic transducer which generates the transmitted signal and wherein the data analysis means responds to the fluctuations in the received ultrasound waveform by sensing a predetermined polarity reversal of the waveform following the onset

triggered by sensing the arrival of the received pulse.

3 An ultrasonic position measuring system according to claim 2, wherein the data analysis means are operative to register the occurrence of the transition for which the predetermined polarity reversal is the fifth transition through zero signal.

4 An ultrasonic position measuring system according to claim 2, wherein the data analysis means are controlled by a systems clock and a counter which control the sampling of incoming signal data at B at a sequence of time intervals related to distance from A and which comprise a data store and comparator means for separately sensing the event when a signal arrives and the event when the signal undergoes the predetermined polarity reversal, the first event triggering the reversal count determining the selection of the reversal of the second event, the timing of the second event being registered in the memory of the data store and the timing data so registered providing the measure of distance indicated by the system.

5 An ultrasonic position measuring system according to claim 4, wherein the data analysis means comprise

also a data averaging memory which registers a profile of the received signal waveform averaged by recycling memory data through a summing unit which combines a weighted measure of the recycled data with current input data, the means for sensing the event when a signal arrives and the event when the signal undergoes the predetermined polarity reversal being responsive to the signal represented by the data-averaged waveform profile as registered in the data averaging memory, whereby to afford a measure of AB based on an average generated from a muliplicity of recurrent pulses of ultrasonic transmissions.

6 An ultrasonic position measuring system according to claim 5, wherein the data analysis means includes a buffer memory for temporary storage of incoming signal waveform profile data provided by the currently incoming pulse, and the means for detecting the predetermined polarity reversal comprise a comparator means sensitive to control data from the data averaging memory which governs the determination of the predetermined polarity reversal in incoming data registered in the buffer memory.

7 An ultrasonic position measuring system according to claim 6, wherein the data averaging memory includes two memory banks which are controlled so as to

cooperate in responding alternately to incoming signal profile data and adjusting the averaged data stored in memory, data at successive addresses representing distance measurement being read from one memory bank and merged with data from the buffer memory before storage in the other memory bank.

8. An ultrasonic position measuring system substantially as described herein with reference to Figures 1 to 6 of the accompanying drawings.

'atents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number
9025164.6

Relevant Technical fields

(i) UK Cl (Edition K) G1G (GER, GRA, GRE, GSB)

(ii) Int Cl (Edition 5) G01S 11/14, 5/18

Search Examiner

R C HRADSKY

Databases (see over)

(i) UK Patent Office

(ii)

Date of Search

12 FEBRUARY 1991

Documents considered relevant following a search in respect of claims 1-8

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
A	GB 2156986 A (LICENTIA P-V) note Figure 3 a	1
A	EP 0180652 A1 (HONEYWELL) see whole document	1

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family, corresponding document.

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).

Published 1992 at The Patent Office, Concept House, Cardiff Road, Newport, Gwent NP9 1RH. Further copies may be obtained from Sales Branch, Unit 6, Nine Mile Point, Cwmfelinfach, Cross Keys, Newport, NP1 7HZ. Printed by Multiplex techniques ltd, St Mary Cray, Kent.